

User's Guide on the Use of GOES-8, SSM/T and SSM/T-2
Radiance Measurements in MM5: The Radiative Transfer
Models, and Their Tangent Linear and Adjoint operators

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1 Introduction

Atmospheric data assimilation merges observational information from a variety of sources with the known background field to yield an estimate (analysis) of the atmospheric state on regular model grid at some time(s). It is carried out based on some forms of statistical consideration dealing with a diverse set of information: observations, physical or statistical models, and known analyses at previous times. Many meteorological satellite observations, which are often not the direct measurements of the analysis variables, are now made available for use in numerical weather prediction. This documentation deals with satellite observed radiance measurements and the use of them in a mesoscale forecast model.

Values of satellite radiance depends on the atmospheric thermodynamic state (temperature, humidity, and pressure fields). A forward model (called an observation operator) which relates the model fields to a specific observational quantity is required to extract useful information from these (indirect) measurements for improving the quality of atmospheric data analysis and numerical weather prediction. For satellite radiance, we call such a forward model as a radiative transfer model (RTM). The atmospheric thermodynamic state is the input to these RTMs and the radiances at various frequencies are output. Once a RTM is formulated which links the analysis variables to radiance, the tangent linear of the RTM produces the perturbation in the radiance given perturbations in input variables, and the adjoint of the RTM provides the sensitivity of the radiance with respect to model variables in the computationally most effective way. With these components (the RTM, its tangent linear model and adjoint model), one can technically include the radiance measurements into any existing data assimilation system using a variational formulation, such as a 3D-Var or 4D-Var system (Zou et al., 1999).

There are many considerations that are related to the formulation of the forward model. These include understanding the physics behind the measurement, the physics and numerics of the forward model and its discretization, the computational requirement, the forward model error, and the observation error. This documentation describes the development of the RTM and its tangent linear and adjoint models for the use of new Geostationary Operational Environmental Satellite (GOES) system, Defense Meteorology Satellite Program (DMSP)

Special Sensor Microwave Temperature sounder SSM/T, the Special Sensor Microwave Water Vapor Profiler SSM/T-2. The RTM is the major forward (observation) operator which calculates the radiance based on the model state and the input of the satellite geometry. The tangent linear and adjoint of the forward observation operator is developed according to the method described by Navon et al. (1992) and is also described in this documentation.

Satellites are a critical part of the global observing system, particularly over oceans where very few other observations exist. While temperature and humidity retrievals from satellite observations have played some roles in numerical weather prediction, more benefits may be obtained by the direct use of the rawer form of data, which could be handled with the introduction of adjoint techniques into meteorology (Le Dimet and Talagrand, 1986). This document is organized as follows: A brief description of GOES-8, SSM/T and SSM/T2 Satellites is provided in Section 2. The RTMs are presented in Section 3. Section 4 reports the development of the tangent linear and adjoint of RTMs and the correctness test results. The linkage of the RTM and the RTM adjoint operator is given in Section 5. The last section, Section 6, provides a description of the source codes.

2 Brief description of the GOES-8, SSM/T and SSM/T2 satellite measurements

2.1 SSM/T

The SSM/T is a seven channel microwave sounder, designed to provide global and synoptic scale soundings of temperature throughout the troposphere and lower stratosphere. All seven channels (50.50, 53.20, 54.35, 54.90, 58.40, 58.825, and 59.40 GHz) are within the 50-60 GHz oxygen band. The upwelling atmospheric microwave radiance can be detected by the instrument.

The first SSM/T instrument was flown in June 1979 on Block 5D spacecraft and again launched in November 1983 aboard the Air Force Block 5D satellite and is currently operational. To date, the SSM/T sensor was flown aboard DMSP F8, F9, F10, F11, F12 and F13 satellite.

The SSM/T produces a swath of approximately 1600-km wide. The satellite completes a single orbit in approximately 104 minutes, resulting in approximately 14 orbits per day. Each orbit covers a different area of the earth, except poleward of 57 degree latitude. The objective of SSM/T is designed to provide global, synoptic scale soundings of temperature throughout the troposphere and lower stratosphere. The measurements are usually within 1K (rms error) of the brightness temperatures and independent of cloud cover. More information can be found in Louis et al. (1992).

2.2 SSM/T-2

The first operational microwave water vapor sounder SSM/T2 was placed in orbit on 28 November 1991. It is a scanning, five channel, passive and total power microwave radiometer system. The SSM/T-2 consists of five channels: three water vapor channels centered around the 183.31 GHz water vapor line, a 91 GHz channel and a 150 GHz channel. The SSM/T-2 observation rate is 7.5 scans per minute. There are 28 observations (beam positions) per scan for each of the five channels, with each observation having a spatial resolution of approximately 48 Km. All five channels have coincident centers. The total swath width for the SSM/T-2 is approximately 1500 Km. The observations are made at a spatial resolution of approximately 45 Km. Some other parameters and the satellite calibration and validation can be referred to Falcone et al., 1992.

Because taking advantage of the reduced sensitivity of the microwave region to cloud attenuation, the SSM/T-2 sensor aboard DMSP satellite introduced a new source of data for analyzing water vapor globally even under overcast conditions. Through SSM/T-2, a space borne instrument, the global monitoring of the concentration of water vapor in the atmosphere under all sky conditions are provided.

Although TIROS Operational Vertical Sounder (TOVS) satellite can also provide water vapor concentration, its derived moisture profiles are limited to the atmosphere above the cloud top and gaps between clouds because TOVS relies on HIRS2 (High Resolution Infrared Sounder Number 2) infrared channels for water vapor retrievals. It therefore have greater advantage to use SSM/T-2 water vapor sounding than TOVS in analyzing moisture distribution in numerical weather prediction and modeling.

2.3 GOES-8

GOES-8 is the first of a new generation of Geostationary Operational Environmental Satellites. GOES-8 was launched on 13 April 1994. It is earth-oriented to improve instrument performance and enable more efficient data gathering by both the imager and sounder. Comparing with the proceeding GOES series, the updated system of GOES-8 are greatly improved (cf. Menzel and Purdom, 1994).

The GOES-8 imager has five-band multispectral capability with high spatial resolution. The five spectral bands are (a) 0.52-0.72 (visible), (b) 3.78-4.03 (shortwave infrared window), (c) 6.47-7.02 (upper-level water vapor), (d) 10.2-11.2 (longwave infrared window), and (e) 11.5-12.5 (infrared window with slightly more sensitivity to water vapor than the other infrared windows). The GOES-8 imager provides visible data with about 1 Km resolution as GOES-VAS but with a stable linear response and 10-bit precision, improving upon the GOES-VAS variable nonlinear 6-bit response. The GOES-8 imager also provides infrared imagery simultaneously in four thermal bands instead of the two or three bands available in the imaging mode from GOES-VAS. For nadir view, the imager's infrared window bands are at 4 Km horizontal resolution (water vapor band is at 8 Km), while the GOES-VAS infrared window band is at 6.9 Km (other bands are at 13.8 Km).

In addition, the GOES-8 sounder is now an independent instrument and capable of supporting routine operations for the first time. It includes 18 thermal infrared bands plus a low-resolution visible band, compared to the 12 infrared bands plus a visible band on GOES-VAS. The new spectral bands, at wavelengths never obtained before in geosynchronous orbit, are sensitive to temperature, moisture, and ozone. The full-time availability of the GOES-8 sounder enables operational sounding products for the first time; this has the potential for contributing significantly to mesoscale forecasting over the conterminous United States, monitoring thermal winds over oceans and supplementing the Automated Surface Observing System (ASOS) with upper-level cloud information. The new satellite provides many advancements over the previous geostationary weather satellites with its better spatial resolution, improved radiometric accuracy, additional spectral channels, separate imager and sounder instruments, and more flexibility in data collection scenarios. There

is much excitement about GOES-8 data, and significant improvements in data quality and information content await the user (Smith and Lee, 1995).

3 Radiative transfer models

The radiative transfer model is an essential component of a system for exploiting the satellite data in the thermo-dynamic retrieval as well as in the 3D/4D-var assimilation. Through a RTM, the satellite brightness temperatures emitted from the atmosphere and the surface can be computed from the atmospheric profiles of temperature and specific humidity, surface pressure and sea surface winds. The RTM for GOES-8 was described in Zou et al. (1999). The RTM for SSM/T and SSM/T-2 is very similar to that of GOES-8.

The major difference between the GOES-8 radiative transfer model and SSM/T and SSM/T-2 radiative transfer model is as follows: For GOES-8, the surface emissivity ϵ_α was assumed to be 0.97 for channels 1-12 and 0.96 for channels 13-18 over land, and 0.98 for all channels over ocean. For SSM/T and SSM/T-2, the surface emissivity ϵ_α is taken a constant (0.95) over land for simplicity. However, the surface emissivity over sea for SSM/T and SSM/T-2 is more complicated and is strongly related to the sea surface wind because wind roughens the sea surface and produces foams and therefore cause changes in sea surface emissivity. An up-to-date sea surface emissivity model which reflect the relationship between wind speed and sea surface emissivity with better accuracy was developed by Kohn (1995) and is be used to deal with the sea surface emissivity.

4 Development of the TGL and ADJ Model

Having satellite RTMs, we proceed with the development of the tangent linear and adjoint versions of the raytracing operator, which are required for the direct use of GOES-8, SSM/T and SSM/T-2 satellite radiance measurements in a variational data analysis system.

4.1 TGL operators

First of all, the original nonlinear RTM is linearized around the forward RTM state to obtain the tangent linear RTM (TGL-RTM). If we write the RTM as

$$R = \mathbf{H}(X), \quad (4.1)$$

the TGL-RTM is

$$\delta R = \mathbf{H}'(X)\delta X, \quad (4.1)$$

where X is the model state vector and δX is the perturbation to X , δR is the calculated perturbed radiance. H' is the related TGL-RTM operator. The linearization is carried out directly at the coding level in order to keep an exactly same structure as the original RTM. The rules will presented below, which is easily understandable with the knowledge of calculus. For example, in a FORTRAN program a typical assignment statement has the form of

$$y = f(x_1, x_2, x_3, \dots, x_m), \quad (4.2)$$

which y is a single output variable, $x_1, x_2, x_3, \dots, x_m$ are input variables, and f is a differentiable function. For simplicity, here mathematical expressions have been used to represent the FORTRAN statement. Chain rule gives

$$\delta y = \frac{\partial f}{\partial x_1} \delta x_1 + \frac{\partial f}{\partial x_2} \delta x_2 + \dots + \frac{\partial f}{\partial x_m} \delta x_m, \quad (4.3)$$

which is the TGL statement where the derivatives are calculated in which values for the variables are calculated from the unperturbed model state (same as in the forward RTM), and the quantities with δ are TGL variables.

To check the correctness of the TGL code, we used the Taylor expansion for the RTM

$$\mathbf{H}(X + \alpha \Delta X) = \mathbf{H}(X) + \alpha \mathbf{H}'(X) \Delta X + O(\alpha^2) \quad (4.4)$$

and

$$F(\alpha) = \frac{\mathbf{H}(X + \alpha \Delta X) - \mathbf{H}(X)}{\alpha \mathbf{H}'(X) \Delta X} = 1 + O(\alpha) \quad (4.5)$$

The equation (4.5) means that $F(\alpha)$ should linearly approach unit 1 when α approaches zero. The equation (4.5) is used to check the correctness of the TGL code against the nonlinear RTM. The equation (4.5) should be verified for all the possible input vector of the control variables.

4.2 ADJ code development

The word “adjoint” comes from the inner product in linear space. A linear operator, L^* , is said to be the adjoint of L if, for all x and y in a linear space having

$$\langle y, Lx \rangle = \langle L^*y, x \rangle \quad (4.6)$$

where $\langle \rangle$ represents an inner product. In Euler space, $L^* = LT$.

According to the definition above, the adjoint model corresponding to Eq. (4.1) is

$$\delta X^* = \mathbf{H}^*(X) \delta R^* \quad (4.7)$$

where the variable with subscript $*$ is the adjoint variable and \mathbf{H}^* is adjoint operator of the radiative transfer model.

The Fortran code for the adjoint RTM (ADJ-RTM), i.e., the operator \mathbf{H}^* , is developed from the TGL code directly following the method proposed by Navon et al. (1992). For such a method, it is very important to know the input and output variables before writing the adjoint code. A careful analysis of all input variables to find out whether it is reused or not is also a crucial step. If, for example, the input variable x is reused and y is not in the following statement

$$z = ax + by$$

where a and b are constants and z is output variable, the related adjoint code should be

$$x = x + az$$

$$y = bz$$

Because some constant coefficients in the TGL model (4.1) is calculated from the nonlinear RTM state, a great attention must be paid to the coefficients used in the adjoint code to check if they are consistent with the TGL code. After finishing the adjoint code, a special procedure must be taken to verify the correctness of the adjoint code. According to Navon et al. (1992), there are two ways to check the correctness of the adjoint. First, at any

level of the code, the development of the discrete adjoint model can be checked by applying the following identity:

$$(AQ)^T(AQ) = A^T[A^T(AQ)] \quad (4.8)$$

where Q represents the input of the original code, and A represents either a single DO loop or a subroutine. A nother verification of the the correctness of the adjoint code is carried based on the RTM (instead of TGL-RTM) through correstness check of the gradient calculation described below. Let

$$R(X + \alpha h) = R(X) + \alpha h^T \Delta R(X) + O(\alpha^2) \quad (4.9)$$

be a Taylor expansion of the cost function. The term α is a small scalar, and h is a vector of unit length. Rewriting the above formulas, a function of α can be defined as

$$\phi(\alpha) = \frac{J(X + \alpha h) - J(X)}{\alpha h^T \nabla J(X)} = 1 + O(\alpha) \quad (4.10)$$

For values of α that are small but not too close to the machine zero, one should expect to obtain a value for $\phi(\alpha)$ that is close to 1. The behavior of $\phi(\alpha)$ is similar to that of $F(\alpha)$ for the tangent linear check mentioned in section 4.1.

4.3 Numerical results of the correctness check of TGL-RTM and ADJ-RTM

In order to check the TGL and ADJ code of the RTM, we use a typical atmospheric sounding for the brightness temperature calculation of SSM/T, SSM/T-2 and GOES-8. Fig.1 is the vertical profiles of temperature and humidity, with values of temperature available at 40 RTM layers and humidity at the lowest 21 layers. The tick marks on the vertical coordinate represent the pressure level of the RTM. Because the humidity above 100 hPa is very difficult to detect and its importance for the calculation of radiance or brightness temperature is small, usually the lowest 21 layers humidity data is enough.

Besides the temperature and humidity profile, surface and surface skin temperature, surface humidity, surface pressure and ocean surface winds are also needed by RTM. For verification of the TGL-RTM and ADJ-RTM codes, values of these surface quantities are

303 K for the surface temperature, 310 K for the surface skin temperature, 21.47 g/kg for the surface humidity, 1001 *hPa* for the surface pressure and 0 *m/s* for the ocean surface wind. These values of the input variables can be varied so that we can test the TGL-RTM and ADJ-RTM codes with a series of different input data.

Figure 2a gives the checking results of TGL-RTM code for all the DMSP microwave channels of SSM/T, SSM/T-2, and Fig. 2b for all the infrared channels of GOES-8. The checking formula was (4.5). It is obvious that $F(\alpha)$ shown in Fig.2 approaches 1 linearly when α becomes smaller and smaller but not too close to the machine zero. When we turn off some satellite or some channels in RTM code, the checking results were very similar. These tests shows that the TGL-RTM codes for both the SSM/T, SSM/T-2 and GOES-8 radiance calculations are correct.

The ADJ-RTM code was developed based on the TGL-RTM code, realizing the transpose operation made to the TGL-RTM operator. It was developed at the coding level based on the method described by Navon et. al. (1992). The equality in (4.8) is used to check the correctness of ADJ-RTM. For convenience we called the left side of (4.8) left term and the right side of (4.8) right term. Random perturbations are given for the input of TGL-RTM. The basic state uses the same values of input to the TGL-RTM check described above, and a variation of it. For DMSP SSM/T, SSM/T-2 RTM, we set up 7 types of basic state and type 1 is just the case in Fig.1 and surface parameters listed in Table 2. The checking results are also shown in Table 2 for SSM/T, SSM/T-2 transfer (all channels). In Table 2, the surface temperature, surface skin temperature, surface humidity, surface pressure, surface emissivity and ocean surface wind are donated by T_s , T_{sk} , q_s , p_s , e_s and w_s , respectively. All the testing runs use 0 degree scan angles for SSM/T and SSM/T-2 sounder except Type 7 testing design.

For GOES-8 satellite, we used 8 types of basic state to check the correctness of ADJ-RTM. Again, the random perturbation was used as input to TGL-RTM. The eight types of basic state is described in Table 3. The ADJ-RTM test results are presented in Table 3 as well. In Table 3 all the parameters have the same meaning to Table 2 and *theta* denotes zenith angle of the satellite.

Table 1: Results of ADJ-RTM tests for SSM/T, SSM/T-2

	Basic state	Left Term	Right term
1	Land case: Temperature and humidity profile as in Fig.1, $T_s=303\text{K}$, $T_{sk}=310\text{K}$, $q_s=21.47\text{g/kg}$, $p_s=1001\text{ hPa}$, and $e_s=0.95$	0.1133622831412E+04	0.1133622831412E+04
2	As in Type 1 but $T_{sk}=280\text{K}$	0.1143187819105E+04	0.1143187819105E+04
3	As in Type 1 but $p_s=1010\text{ hPa}$	0.6406206915060E+03	0.6406206915061E+03
4	Ocean case: Temperature and humidity profile as in Fig.1, $T_s=303\text{K}$, $T_{sk}=310\text{K}$, $q_s=21.47\text{g/kg}$, $p_s=1001\text{ hPa}$, e_s is related to atmospheric state and $w_s, w_s=0\text{ m/s}$	0.1880183207477E+03	0.1880183207477E+03
5	As in Type 5 but $p_s=1050\text{ hPa}$	0.6091167936610E+03	0.6091167936610E+03
6	As in Type 4 but humidity (including surface humidity) is reduced to 10 cent of Type 4	0.8667568777563E+04	0.8667568777566E+04
7	As in Type 4 but the scan angel for SSM/T and SSM/T-2 are 45 degree	0.3247775619865E+04	0.3247775619865E+04

From Table 2 and 3, we find that the left term equals to the right term (4.8) with the machine accuracy (13 digital accuracy on Cray computers). This implies that the ADJ-RTM code is exactly the adjoint of the TGL code. The gradient check, which checks the correctness of both TGL-RTM and ADJ-RTM, will be presented in the following section along with the definition of cost function.

Table 2: Results of the ADJ-RTM tests for GOES-8

	Basic state	Left Term	Right term
1	Temperature and humidity profile as in Fig.1, $T_s=303\text{K}$, $T_{sk}=310\text{K}$, $p_s=1001\text{hPa}$, $e_s=1.$, and $\theta=0$ degree	0.6164008528155E+03	0.6164008528154E+03
2	As in Type 1 but $T_{sk}=280\text{K}$	0.6105858094283E+03	0.6105858094283E+03
3	As in Type 1 but $p_s=990$ hPa	0.4124217154425E+03	0.4124217154424E+03
4	As in Type 1 but $e_s=0.95$ hPa	0.2209597309989E+03	0.2209597309989E+03
5	As in Type 1 but $p_s=1050$ hPa	0.4036828550092E+03	0.4036828550092E+03
6	As in Type 1 but humidity is reduced to 10 percent of Type 1	0.1787584544465E+04	0.1787584544465E+04
7	As in Type 1 but $\theta=40$ degree	0.3437159805102E+03	0.3437159805102E+03
8	As in Type 1 but $\theta=55$ degree	0.8832127004302E+03	0.8832127004301E+03

5 Linking RTMs and ADJ-RTMs to MM5

The RTM requires the input of temperature values from 0.1 to 1000 hPa at 40 vertical layers, specific humidity values from 70 hPa to 1000 hPa at 21 vertical layers, plus surface pressure, surface air, skin temperature, and surface wind. They are provided by the MM5 model output and NCEP global analysis. The vertical interpolation and extrapolation are required to link the RTM input to the MM5 model output and NCEP analysis because of the differences in the vertical coordinates in RTM and MM5.

There are three possibilities to prepare the temperature and humidity profile of the RTM from MM5 output.

- For the RTM layers between the MM5 top and bottom layers, the variables are linearly interpolated from the MM5 variables on the logarithm of pressure coordinate.
- For the RTM layers above the MM5 top layer, the NCEP analysis is used for the linear interpolation. The NCEP global analysis and the NCEP stratospheric analysis (up to

0.4 hPa) are provided twice a day. The analysis closest to the forecast time is used for the brightness temperature calculations.

- c. For the RTM layers below MM5 bottom layer and above the NCEP stratospheric analysis top (0.4 hPa), a simply linear extrapolation is used to generate the necessary input data for RTM. Data at these layers have minor influence on the brightness temperatures. In fact, the specific humidity above 0.4 hPa is very small. The temperature and humidity below the lowest model level of MM5 and above the Earth's surface are extrapolated from the MM5 output.

The surface air temperature, surface humidity and surface wind are extrapolated from the MM5 output. The surface pressure and surface skin temperature are the direct MM5 output variables.

The linkage of ADJ-RTMs to the MM5 adjoint model is straightforward. Readers are recommended to the documentation by Zou et al. (1977).

6 Source Code Description for the Radiative Transfer Model of GOES Infrared Sounder

The source codes for the RTM and its tangent linear and adjoint model are described in this section. The forward RTM program is based on the Eyre-Woolf adaptation for AMSU of the McMillin-Fleming fast transmittance model (Eyre and Woolf, 1988). The code was revised and the transmittance coefficients for GOES were generated by Atmospheric and Environmental Research, Inc. in Cambridge Massachusetts. The driver and the subprograms it calls were revised by Alan Lipton and George Modera at Phillips Laboratory.

6.1 Radiative Transfer Code

The RTM code is an operator calculating the radiances or brightness temperatures by solving the radiative transfer equation (Lion, 1988). Based on the original code developed by Eyre (1991), modifications were made to add capacity for water vapor mixing ratio extrapolation.

The RTM was altered to interface with University of Wisconsin routines for Planck function and its inverse, and to fit to the GOES channel spectral response functions. The handling of the surface term in the radiative transfer integration was changed to be more faithful to the specified surface pressure and to make use of a specified surface air temperature.

6.1.1 XRTDRV

The main routine XRTDRV is the drive for the whole RTM for computation of radiances and brightness temperatures for infrared GOES sounder. The observed rawinsonde profile or model-calculated atmospheric state can be used as the input and the output of the program is the radiances or brightness temperatures of the GOES infrared Sounder at the 18 Channels.

```
SUBROUTINE XRTDRV(JCHAN,ZEANG,KDO,  
                  XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX,  
                  TB,RAD)
```

Arguments description:

a Input constants given as calling arguments:

JCHAN(MXCH):	INTEGER, Switch to turn on (1) or off (0) computations for each channel
ZENANG:	REAL, Local zenith angle of the satellite (degrees)
KDO(3):	REAL, Switch for including absorption due to well-mixed gases, water vapor, ozone, respectively (1=y,0=n)

b Input variables:

XTSFC: REAL, Surface air temperature (K)
 XTSKIN: REAL, Surface skin temperature (K)
 XPSFC: REAL, Surface pressure (mb)
 XTEMP(NL): REAL, Atmospheric temperature (K) from 0.1 to 1000 mb
 XWMIX(NW): REAL, Water vapor mixing ratio (g/kg) from some level
 (determined by NW) to 1000 mb
 XOMIX(NL): REAL, Atmospheric ozone mixing ratio (parts per million
 in volume-PPMV) from 0.1 to 1000 mb (reference
 profile is used if all values are set to zero)

c Output variables:

TB(MXCH): REAL, Brightness temperatures (K) for GOES channels
 RAD(MXCH): REAL, Radiances [$\text{mW}/(\text{m}^2 \text{ sr cm}^{-1})$] for GOES channels

6.1.2 XINIT

The Subroutine XINIT determines the index of the next pressure level below the surface and transfers profile data into working arrays.

```

SUBROUTINE XINIT(XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX)
COMMON /PRFSTD/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON /SURF/NSURF,TAUSFC,TGRND,TSFC,PSFC
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
  
```

Arguments description:

XTSFC: REAL, Surface air temperature (K)
 XTSKIN: REAL, Surface skin temperature (K)
 XPSFC: REAL, Surface pressure (mb)
 XTEMP(NL): REAL, Atmospheric temperature (K) from 0.1 to 1000 mb
 XWMIX(NW): REAL, Water vapor mixing ratio (g/kg) from some level
 (determined by NW) to 1000 mb
 XOMIX(NL): REAL, Atmospheric ozone mixing ratio (parts per million
 in volume-PPMV) from 0.1 to 1000 mb (reference
 profile is used if all values are set to zero)

All the arguments listed above are input variables for this subroutine.

Common Blocks description:

TEMP(NL): REAL, Working arrays, Temperature for the 40 layers
 WMIX(NL): REAL, Working arrays, Water vapor mixing ratio for the 40 layers
 OMIX(NL): REAL, Working arrays, Ozone mixing ratio for the 40 layers
 NSURF: INTEGER, next pressure level below the surface
 TAUSFC: REAL, Surface transmittance, not used in this subroutine
 TGRND: REAL, Surface skin temperature, not used in this subroutine
 TSFC: REAL, Surface air temperature
 PSFC: REAL, Surface pressure
 PREF(NL): REAL, The 40 layers pressure value (hPa)
 TREF(NL): REAL, Reference temperature for the 40 layers
 WREF(NL): REAL, Reference water vapor mixing ratio for the 40 layers
 OREF(NL): REAL, Reference ozone mixing ratio for the 40 layers

6.1.3 XULMR

XULMR is a subroutine which generates the high level mixing ratio according to the humidity profile below 70 hPa. Extended mixing ratio profile from the highest level at which data are given are at 70 hPa. The level is controlled by the parameter NW in XINIT. Stratospheric value of the mixing ratio is 0.002 g/kg, with cubic decay of pressure from the value at the highest input level to this value.

SUBROUTINE XULMR(NWP)

There is only one argument in subroutine XULMR, NWP. It is the number of levels at which water vapor mixing ratio has input value.

6.1.4 REFPROF

REFPROF is the block data routine to specify the 40 layer pressures and the reference temperature, water vapor mixing ratio, and ozone mixing ration for the 40 layers.

BLOCK DATA REFPROF

Common block /REFATM/PREF,TREF,WREF,OREF relates these data to other sub-routines.

No Arguments.

6.1.5 XTK

This subroutine is the new Eyre adaption of mcmillin-fleming fast transmittance model. The influence of water vapor and ozone were included in the calculation of the transmittance.

```
SUBROUTINE XTK(KANAL,TAU,THETA,NEWP,KDO)
```

```
COMMON /PRFSTD/T(NL),W(NL),O(NL)
```

```
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
```

Arguments description:

KANAL: INTEGER input constant,
GOES channel which the transmittance will be calculated

TAU: REAL output,
Transmittance at 40 layers

THETA: REAL input,
Satellite local zenith angle for the GOES IFOV

NEWP: INTEGER input,
Logical variable to judge if the atmospheric profile is new

KDO: REAL input constant,
Switch for including absorption due to well-mixed
gases, water vapor, ozone, respectively (1, yes; 0, no)

Common Blocks description:

T(NL):	Temperature profile at 40 layers
W(NL):	Water vapor mixing ratio at 40 layers
O(NL):	Ozone mixing ratio at 40 layers
PREF(NL), TREF(NL), WREF(NL), OREF(NL):	AS the same as in routine XINIT

6.1.6 XSFCTAU

This subroutine XSFCTAU calculates the surface transmittance to the space. The method to calculate the surface transmittance is a simple one, interpolation or extrapolation.

```

SUBROUTINE XSFCTAU(TAU)
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
COMMON/SURF/NSURF,TAUSFC,TGRND,TSFC,PSFC

```

There is only one argument in the subroutine, TAU. It is an input variable, the 40 layer transmittances. The output variable is TAUSFC which appears in the common block /SURF/.

Common Blocks description:

NSURF: INTEGER, next pressure level below the surface
TAUSFC: REAL, Surface transmittance, not used in this subroutine
TGRND: REAL, Surface skin temperature, not used in this subroutine
TSFC: REAL, Surface air temperature
PSFC: REAL, Surface pressure
PREF(NL): REAL, The 40 layers pressure value (hPa)
TREF(NL): REAL, Reference temperature for the 40 layers
WREF(NL): REAL, Reference water vapor mixing ratio for the 40 layers
OREF(NL): REAL, Reference ozone mixing ratio for the 40 layers

6.1.7 XTB

This subroutine is used to calculate the radiances or brightness temperatures for the GOES sounder by integration of the radiative transfer equation. Radiance and brightness temperature are related by the Planck function. Therefore, in this subroutine, calls for the calculation of planck function and visa versa are needed. This is implemented by the two subroutine PLANGO and BRITGO.

```
SUBROUTINE XTB(KCHAN,TAU,ESFC,TB,RAD)
COMMON /PRFSTD/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON /SURF/NSURF,TAUSFC,TGRND,TSFC,PSFC
```

Arguments description:

KCHAN: INTEGER input constant,
Channel which the radiance or broghtness is calculated

TAU: REAL iuput variable,
Atmospheric transmittances for the 40 layers

ESFC: REAL input constant,
Surface emissivity for each channel

TB: REAL output variable,
Brightness temperature for the channel of GOES sounder

RAD: REAL output variable,
Radiance for the channel of GOES sounder

Common Blocks description:

TEMP(NL): REAL, Working arrays, Temperature for the 40 layers

WMIX(NL): REAL, Working arrays, Water vapor mixing ratio for the 40 layers

OMIX(NL): REAL, Working arrays, Ozone mixing ratio for the 40 layers

NSURF: INTEGER, next pressure level below the surface

TAUSFC: REAL, Surface transmittance

TGRND: REAL, Surface skin temperature

TSFC: REAL, Surface air temperature

PSFC: REAL, Surface pressure

The subroutine XTB is called by XRTDRV, the main driver program.

6.1.8 GET_CFN

This subroutine is used to read in the "dry", "wet", and ozone transmittance coefficients.

SUBROUTINE GET_CFN(IUDRY,IUWET,IUOZO)

Arguments description:

IUDRY: INTEGER, Input unit for 'dry' transmittance coefficients

IUWET: INTEGER, Input unit for 'wet' transmittance coefficients

IUOZO: INTEGER, Input unit for ozone transmittance coefficients

6.1.9 GET_PLANCK

This subroutine is used to read in the coefficients in University of Wisconsin SSEC GOES Planck calculations. The file was extracted from the SSEC binary file.

SUBROUTINE GET_PLANCK(IUPC,NGOES)

Arguments description:

IUPC: INTEGER, Input unit for Planck function coefficients

NGOES: INTEGER, Satellite ID number, GOES-8 or 9

6.1.10 PLANGO

PLANGO calculates the GOES/I-M radiance from brightness temperature for the channel.

SUBROUTINE PLANGO(RAD,T,K)

Arguments description:

RAD: REAL output variable, GOES radiance for channel K

T: REAL input variable, Temperature in Kelvins

K: The channel the radiance is calculated

6.1.11 BRITGO

BRITGO calculates the GOES/I-M brightness temperature from the radiance for the channel.

SUBROUTINE BRITGO(BRT,R,K)

Arguments description:

BRT: REAL output variable, GOES brightness temperature for channel K

R: REAL input variable, Radiance for the channel K

K: The channel the brightness temperature is converted

6.2 Tangent Linear and Adjoint Code

The tangent linear code is developed from the nonlinear RTM code. The adjoint code is written exactly from the tangent linear code. Therefore the tangent linear and adjoint codes are similar in their structure. In the sub-section, we give some description of the tangent linear and adjoint codes together. In the tangent linear and adjoint codes, there appear the basic states and the perturbed variables. The basic states are exactly the variables in the non-linear forward model, but treated as the constants in the tangent linear and adjoint code.

For the symbol convention, we used "L" prefixed the nonlinear subroutine for the tangent linear subroutine, and "A" prefixed the nonlinear subroutine for the adjoint subroutine. All the basic states used in the tangent linear and adjoint codes are suffixed with "9".

6.2.1 LXRTDRV and AXRTDRV

The tangent linear code for the nonlinear subroutine XRTDRV is LXRTDRV and its adjoint code is AXRTDRV.

```
SUBROUTINE LXRTDRV(JCHAN,ZENANG,KDO,
                  XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX,TB,RAD,
                  XTSFC9,XTSKIN9,XPSFC9,XTEMP9,XWMIX9,XOMIX9)

SUBROUTINE AXRTDRV(JCHAN,ZENANG,KDO,
                  XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX,TB,RAD,
                  XTSFC9,XTSKIN9,XPSFC9,XTEMP9,XWMIX9,XOMIX9)
```

In the subroutines, JCHAN ,ZENANG and KDO are the same to that used in the forward radiative transfer driver routine. Different from the nonlinear forward code, XTSFC, XTSKIN, XPSFC, XTEMP, XWMIX, XOMIX, TB, RAD in the tangent linear and adjoint codes are perturbed variables.

XTSFC: REAL, Surface air temperature perturbation (K)
 XTSKIN: REAL, Surface skin temperature perturbation (K)
 XPSFC: REAL, Surface pressure perturbation (mb)
 XTEMP(NL): REAL, Atmospheric temperature perturbation (K) for 40 layers
 XWMIX(NW): REAL, Water vapor mixing ratio perturbation (g/kg)
 from some level (determined by NW) to 1000 mb
 XOMIX(NL): REAL, Atmospheric ozone mixing ratio perturbation
 (parts per million in volume-PPMV) for the 40 layers
 currently this variable is set to zero
 (ozone at every layer does not change)
 TB(MXCH): REAL, Perturbed brightness temperatures (K) for GOES channels
 RAD(MXCH): REAL, Perturbed radiances [$\text{mW}/(\text{m}^2 \text{ sr cm}^{-1})$] for GOES channels
 XTSFC9: REAL, Basic state of surface air temperature (K)
 XTSKIN9: REAL, Basic state of surface skin temperature (K)
 XPSFC9: REAL, Basic state of surface pressure (mb)
 XTEMP9(NL): REAL, Basic state of atmospheric temperature (K)
 from 0.1 to 1000 mb (40 layers)
 XWMIX9(NW): REAL, Basic state of water vapor mixing ratio (g/kg)
 from some level (determined by NW) to 1000 mb
 XOMIX9(NL): REAL, Basic state of atmospheric ozone mixing ratio
 from 0.1 to 1000 mb (constants currently,
 reference profile is used)

6.2.2 LXINIT and AXINIT

```

SUBROUTINE LXINIT(XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX,
                  XPSFC9,XWMIX9,XOMIX9)

COMMON/PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
COMMON/PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON/SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
COMMON/SURFT/TAUSFC,TGRND,TSFC,PSFC
  
```

```
COMMON/REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
```

```
SUBROUTINE AXINIT(XTSFC,XTSKIN,XPSFC,XTEMP,XWMIX,XOMIX,  
                  XPSFC9,XWMIX9,XOMIX9)
```

```
COMMON/PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
```

```
COMMON/PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
```

```
COMMON/SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
```

```
COMMON/SURFT/TAUSFC,TGRND,TSFC,PSFC
```

```
COMMON/REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
```

Arguments description:

XTSFC:	REAL, Surface air temperature perturbation (K)
XTSKIN:	REAL, Surface skin temperature perturbation (K)
XPSFC:	REAL, Surface pressure perturbation (mb)
XTEMP(NL):	REAL, Perturbed atmospheric temperature (K) from 0.1 to 1000 mb (40 layers)
XWMIX(NW):	REAL, perturbed water vapor mixing ratio (g/kg) from some level (determined by NW) to 1000 mb
XOMIX(NL):	REAL, perturbed atmospheric ozone mixing ratio from 0.1 to 1000 mb (zero currently)
XPSFC9:	REAL, Basic state of the surface pressure (mb)
XWMIX9:	REAL, Basic state of the water vapor mixing ratio
XOMIX9:	REAL, Basic state of the ozone mixing ration

It is worth noting that the common blocks /PRFSTDXT/ and /SURF/ are used to transfer the basic state, while in the nonlinear forward model it is used as the variables. That means that in the tangent linear and adjoint codes the basic state is come form the nonlinear forward calculation exactly. However, we created two other common blocks /PRFSTDXT/ and /SURFT/ to transfer the perturbation variables between the tangent linear and adjoint codes. The common block /REFATM/ is the same to the original in the nonlinear code. /REFATM/ transfers the constants between all the routines (including the nonlinear, tangent linear and adjoint subroutines).

6.2.3 LXULMR and AXULMR

```
SUBROUTINE LXULMR(NWP)
COMMON/PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
COMMON/PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON/REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)

SUBROUTINE AXULMR(NWP)
COMMON/PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
COMMON/PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON/REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
```

There is no big difference in the arguments between the nonlinear, tangent linear and adjoint code for XULMR. The common block /PRFSTDXT/ transfers the basic state from the nonlinear forward calculations and used in the tangent linear and adjoint calculation. /REFATM/ transfers the reference atmospheric profile among the whole system. /PRFSTDXT/ is used to exchange the perturbed variables in the tangent linear and adjoint model.

6.2.4 LXTK and AXTK

LXTK and AXTK are the tangent linear and adjoint subroutine of the transmittance subroutine XTK.

```
SUBROUTINE LXTK(KANAL,TAU,THETA,NEWP,KDO,TAU9)
COMMON /PRFSTDXT/T9(NL),W9(NL),O9(NL)
COMMON /PRFSTDXT/T(NL),W(NL),O(NL)
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)

SUBROUTINE AXTK(KANAL,TAU,THETA,NEWP,KDO,TAU9)
COMMON /PRFSTDXT/T9(NL),W9(NL),O9(NL)
COMMON /PRFSTDXT/T(NL),W(NL),O(NL)
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
```

In the tangent linear code, T, W, and O in the common block /PRFSTDXT/ are input, TAU in the subroutine argument is the output. KANAL, THETA, NEWP, and KDO in the arguments are constant. T9, W9, and O9 appeared in the common block /PRFSTDXT/ and TAU9 in the subroutine argument are basic states.

In the adjoint code, everything is the same except the input variable T, W, and O are now the output variable, the output variable in the tangent linear code, TAU, is the input variable in the adjoint code.

6.2.5 LXSFCCTAU and AXSFCCTAU

```

SUBROUTINE LXSFCCTAU(TAU,TAU9)
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
COMMON/SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
COMMON/SURFT/NSURF,TAUSFC,TGRND,TSFC,PSFC

SUBROUTINE AXSFCCTAU(TAU,TAU9)
COMMON /REFATM/PREF(NL),TREF(NL),WREF(NL),OREF(NL)
COMMON/SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
COMMON/SURFT/NSURF,TAUSFC,TGRND,TSFC,PSFC

```

Arguments:

TAU: Atmospheric transmittance perturbation

TAU9: Basic state of TAU

Common Blocks description:

PREF(NL): REAL, The 40 layers pressure value (hPa)
 TREF(NL): REAL, Reference temperature for the 40 layers
 WREF(NL): REAL, Reference water vapor mixing ratio for the 40 layers
 OREF(NL): REAL, Reference ozone mixing ratio for the 40 layers
 NSURF: INTEGER, next pressure level below the surface
 TAUSFC9: REAL, Basic state of surface transmittance
 TGRND9: REAL, Basic state of surface skin temperature
 TSFC9: REAL, Basic state of surface air temperature
 PSFC9: REAL, Surface pressure basic state
 TAUSFC: REAL, Surface transmittance perturbation
 TGRND: REAL, Surface skin temperature perturbation
 TSFC: REAL, Surface air temperature perturbation
 PSFC: REAL, Surface pressure perturbation

6.2.6 LXTB and AXTB

```

SUBROUTINE LXTB(KCHAN,TAU,ESFC,TB,RAD,TAU9)
COMMON /PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
COMMON /PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON /SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
COMMON /SURFT/NSURF,TAUSFC,TGRND,TSFC,PSFC
  
```

```

SUBROUTINE AXTB(KCHAN,TAU,ESFC,TB,RAD,TAU9)
COMMON /PRFSTDXT/TEMP9(NL),WMIX9(NL),OMIX9(NL)
COMMON /PRFSTDXT/TEMP(NL),WMIX(NL),OMIX(NL)
COMMON /SURF/NSURF,TAUSFC9,TGRND9,TSFC9,PSFC9
COMMON /SURFT/NSURF,TAUSFC,TGRND,TSFC,PSFC
  
```

In the arguments, TAU9 is the basic state of the transmittance at 40 layers. TAU is the perturbed transmittance, an input variable for LXTB and output variable for AXTB. TB and RAD are the perturbed brightness temperature and radiance. For LXTB, TB and RAD are output variable. For AXTB, TB and RAD are both input variables.

KCHAN is the channel at which the satellite data is observed and processed. KCHAN is an input constant. ESFC represents the surface emissivity coefficient. It is a constant in the model.

All the common blocks are the same to that used in LXINT or AXINT.

6.2.7 LPLANGO and APLANGO

```
SUBROUTINE LPLANGO(RAD,T,K,T9)
```

```
SUBROUTINE APLANGO(RAD,T,K,T9)
```

LPLANGO is used to calculate the perturbation of radiance, RAD, from the input of the perturbed temperature T. APLANGO is vice versa. In both subroutines, K is the channel which we want to process and T9 is the basic state of temperature.

6.2.8 LBRITGO and ABRITGO

```
SUBROUTINE LBRITGO(BRT,R,K,R9)
```

```
SUBROUTINE ABRITGO(BRT,R,K,R9)
```

LBRITGO is used to calculate the perturbation of brightness temperature, BRT, from the input of the perturbed radiance R. ABRITGO is vice versa. In both subroutines, K is the channel which we want to process and R9 is the basic state of radiance.

7 Source Code Description for the Radiative Transfer Model of DMSP Microwave sounder, SSM/T and SSM/T-2

Because the code for the DMSP Microwave sounder, SSM/T and SSM/T-2, is similar to the code for GOES-8(9) sounder, we will focus on the difference of the codes between the GOES and DMSP microwave sounder in this section. Basically, there are two big difference in the DMSP microwave code comparing to the GOES code. One is the addition of the cosmic

background radiation term when calculating the brightness temperatures of the microwave channel. The other is that ocean surface emissivity values was replaced with an updated model obtained from Tom Wilheit of Texas A&M University.

7.1 The Radiative Transfer Forward code

The Radiative Transfer Forward code is set up so that one call can produce brightness temperatures for each of the channels in the microwave suite, assuming they all occur at the same location. However, it is possible to make computations for only specific channels by "turning off" channels using the switch in the driver routine.

There are 13 subroutines in the forward model.

7.1.1 DMSPDRV

DMSPDRV is the driver for the computation of brightness temperatures for the DMSP microwave channels. This routine is corresponding to the GOES code XRTDRV.

```
SUBROUTINE DMSPDRV(ILW,T1ANG,T2ANG,TSFC,QSFC,TSKIN,PSFC,WS,  
&                  TINP,QINP,TBMT,TBT2,TBMI)
```

Arguments description:

a Input constants given as calling arguments:

ILW: INTEGER, identifier for Land (1) or water (0).
T1ANG: REAL, Scan angle (degrees) of the SSM/T observation.
T2ANG: REAL, Scan angle (degrees) of the SSM/T-2 observatopn.

b Input variables:

TSFC: REAL, Surface air temperature (K)
 QSFC: REAL, Surface qir water mixing ration (g/kg)
 TSKIN: REAL, Surface skin temperature (K)
 PSFC: REAL, Surface pressure (mb)
 WS: REAL, Surface wind velocity (m/s)
 TINP: REAL, Atmospheric temperature (K) from 0.1 to 1000 mb
 QINP: REAL, Water vapor mixing ratio (g/kg) from some level
 (determined by NW) to 1000 mb

c Output variables:

TBMT(7): REAL, Brightness temperatures (K) for SSM/T
 TBT2(5): REAL, Brightness temperatures (K) for SSM/T-2
 TBMI(7): REAL, Brightness temperatures (K) for SSM/I, never used

7.1.2 Setup of the temperature and water vapor mixing ration for the RTM

To set up the RTM profile of temperature and water vapor mixing ration, the model used the following two subroutines, INIT4 and ULMRJ.

```

SUBROUTINE INIT4(PROF)
COMMON/PRFSTD/PREF(40),TEMP(40),WMIX(40),NREF,TOTO,XLAT
COMMON/SURF/NSURF,TAUSFC,TSFC,TGRND,PSFC
COMMON/MSUFLG/ILOBES,LST,LCLDIN,PTOP,PBOT,WLIQIN
common/extendq/nw,iw0,itsfc,iqsfc,itskn,ipsfc,icld,iclw,iem

SUBROUTINE ULMRJ
COMMON/PRFSTD/PREF(40),TEMP(40),W(40),NREF,TOTO,XLAT
common/extendq/nw,iw0,itsfc,iqsfc,itskn,ipsfc,icld,iclw,iem
  
```

INIT4 has the same function to XINIT in GOES code, and ULMRJ has the same function to XULMR in GOES code. Both subroutines are used to initialize (set up) the profile for the calculation of brightness temperature.

7.1.3 ANGLES

The purpose of this subroutine is to deal with the satellite view parameters for the microwave sounder. It input the satellite scan angle to perform path geometry calculation for satellite viewing earth at nadir angle.

SUBROUTINE ANGLES(ANG,HITE,ZENANG,PATH,SMAX,CRH)

Arguments description:

ANG: Scan angle of the satellite observation
HITE: Satellite height, it is a constant for the specific satellite
ZENANG: Output zenith angle of the satellite observation
PATH: Optical path, an air mass factor
SMAX: Nadir angle of view to earth edge
CRH: Ratio of satellite orbital radius to earth radius

7.1.4 Surface Emissivity Calculation

Unlike GOES satellite RTM described in the previous section, the DMSP microwave code deal with the surface emissivity in different way. The code separates the land use into Land (ilw=1) and Ocean (ilw=0). At land, the surface emissivity is taken as constant. Over ocean, on the other hand, a more updated program from Tom Wilhelm of Texas A&M University is used to calculate the surface emissivity.

The subroutine to calculate the ocean surface emissivity is EDMSP. EDMSP calls ROUGH to calculate the vertical and horizontal emissivities from Cox and Monk at 20m.

SUBROUTINE EDMSP(ANG1,ANG2,TEMP,WS,EM)

SUBROUTINE ROUGH(F,ANGLE,TEMP,PPT,WS,VERT,HORIZ)

EDMSP Arguments description:

ANG1: REAL input constant, Zenith angle for the SSM/T
ANG2: REAL input constant, Zenith angle for the SSM/T₂
TEMP: REAL input variable, Sea surface temperature in Kelvins
WS: REAL input variable, Sea surface wind speed at m/s
EM: REAL output variable, Calculated sea surface emissivity

ROUGH Arguments description:

F: REAL input constant, Frequency in GHz
ANGLE: REAL input constant, INCIDENCE ANGLE IN RADIANS
TEMP: REAL input variable, Sea surface temperature in Kelvins
PPT: REAL input constant, SALINITY IN PARTS PER THOUSAND
WS: REAL input variable, Sea surface wind speed at m/s
VERT: REAL output variable: Emissivity for vertical polarization
HORIZ: REAL output variable: Emissivity for horizontal polarization

7.1.5 Transmittance Calculation

```
SUBROUTINE MCWVTK(KANAL,TAU,NEWP)
COMMON/GEOM1/ANG,ZENANG,PATH,SMAX,CRH
COMMON/PRFSTD/PREF(40),T(40),W(40),NREF,TOTO,XLAT
```

This subroutine corresponds to XTK in GOES code.

Arguments description:

KANAL: The channel which the brightness temperature is calculated
TAU: Output variable: Atmospheric transmittance for the 40 layers
NEWP: Logical variable to judge if the atmospheric profile is new

Common Blocks description:

ANG: Scan angle (Degree)
 ZENANG: Zenith angle (Degree)
 PATH: Optical path
 SMAX: Nadir angle of view to earth edge
 CRH: Ratio of satellite orbital radius to earth radius
 PREF(40): 40 layers RTM pressure value (hPa)
 T(40): 40 layers temperature (K)
 W(40): 40 layers water vapor mixing ratio (g/kg)
 NREF: =40
 TOTO: Total ozone (in dubson)
 XLAT: Latitude of the observation

7.1.6 MCWVTB

```

SUBROUTINE MCWVTB(TAU,TB)
COMMON/PRFSTD/PREF(40),TEMP(40),WMIX(40),NREF,TOTO,XLAT
COMMON/SURF/NSURF,TAUSFX,TSFC,TGRND,PSFC
COMMON/GEOM1/ANG,ZENANG,PATH,SMAX,CRH
COMMON/EMCWV/EMO
common/extendq/nw,iw0,itsfc,iqsfc,itskn,ipsfc,icld,iclw,iem
  
```

This subroutine corresponds to the XTB in GOES code. It calculates the brightness temperature for the DMSP microwave sounder, SSM/T, SSM/T-2 and SSM/I. The principle to calculate the brightness temperature is the same.

Some description:

TAU: Atmpsheric transmittance, an input variable
 TB: Brightness temperature (K), an output variable
 /PRFSTD/: This common block is the same as in the previous description
 /GEOM1/: This common block transfer the datellite geometeory parameters
 It is the same to the description above
 NSURF: next pressure level below the surface
 TAUSFX: Surface transmittance
 TSFC: Surface air temperature
 TGRND: Surface skin temperature
 PSFC: Surface pressure
 EM0: Surface emissivity

7.2 Tangent Linear and Adjoint Code

In this section, only the tangent linear and adjoint codes for the driver subroutine are given. The description of all other tangent linear and adjoint subroutines are omitted. Users can understand the code after reading the description of the tangent linear and adjoint codes of the GOES subroutine, because they are similar.

```
SUBROUTINE LDMSPDRV(ILW,T1ANG,T2ANG,
                   TSFC,QSFC,TSKIN,PSFC,WS,TINP,QINP,
                   TBMT,TBT2,TBMT,
                   TSFC9,QSFC9,TSKIN9,PSFC9,WS9,TINP9,QINP9)
COMMON/PRFSTD/PREF(NREF),TEMP9(NREF),WMIX9(NREF),NREF0,TOTO,XLAT
COMMON/PRFSTD/TEMP(NREF),WMIX(NREF)
COMMON/GEOM1/ANG1,ZENANG1,PATH1,SMAX1,CRH1
COMMON/EXTENDQ/NW0,IW0,ITSFC,IQSFC,ITSKN,IPSFC,ICLD,ICLW,IEM

SUBROUTINE ADMSPDRV(ILW,T1ANG,T2ANG,
                   TSFC,QSFC,TSKIN,PSFC,WS,TINP,QINP,
                   TBMT,TBT2,TBMT,
```

TSFC9, QSFC9, TSKIN9, PSFC9, WS9, TINP9, QINP9)
 COMMON/PRFSTD/PREF(NREF), TEMP9(NREF), WMIX9(NREF), NREF0, TOTO, XLAT
 COMMON/PRFSTD/TEMP(NREF), WMIX(NREF)
 COMMON/GEOM1/ANG1, ZENANG1, PATH1, SMAX1, CRH1
 COMMON/EXTENDQ/NW0, IWO, ITSFC, IQSFC, ITSKN, IPSFC, ICLD, ICLW, IEM

Input Constant Arguments:

ILW: INTEGER input constant,
 identifier for Land (1) or water (0)
 T1ANG: REAL input constant,
 Scan angle (degrees) of the SSM/T observation.
 T2ANG: REAL input constant,
 Scan angle (degrees) of the SSM/T-2 observatopn.

Input and Output Variable Arguments:

TSFC: REAL, Surface air temperature perturbation (K)
 QSFC: REAL, Surface air water mixing ration perturbation (g/kg)
 TSKIN: REAL, Surface skin temperature perturbation(K)
 PSFC: REAL, Surface pressure perturbation (mb)
 WS: REAL, Surface wind velocity perturbation (m/s)
 TINP: REAL, Atmospheric temperature perturbation (K) from 0.1 to 1000 mb
 QINP: REAL, Water vapor mixing ratio perturbation (g/kg) from some level
 (determined by NW) to 1000 mb
 TBMT(7): REAL, Brightness temperatures perturbation (K) for SSM/T
 TBT2(5): REAL, Brightness temperatures perturbation (K) for SSM/T-2
 TBMI(7): REAL, Brightness temperatures perturbation (K) for SSM/I, never used

Input Basic State Arguments:

TSFC9: REAL, basic state of surface air temperature (K)
 QSFC9: REAL, basic state of surface water mixing ration (g/kg)
 TSKIN9: REAL, basic state of surface skin temperature (K)
 PSFC9: REAL, basic state of surface pressure (mb)
 WS9: REAL, basic state of surface wind velocity (m/s)
 TINP9: REAL, basic state of atmospheric temperature (K) from 0.1 to 1000 mb
 QINP9: REAL, basic state of water vapor mixing ratio (g/kg) from some level
 (determined by NW) to 1000 mb

Common Blocks description:

/PRFSTD/: Transfer 40 layer pressure and basic state of the profile
 /GEOM1/: Transfer the satellite geometry parameters
 /EXTENDQ/: Transfer some itentifiers in the RTM model
 /PRFSTDt/: Transfer the perturbed temperature and water vapor mixing ratio
 between the tangent linear and adjoint model
 TEMP is the temperature perturbation at 40 layers
 WMIX is the water vapor mixing ration at 40 layers

In the tangent linear code LDMSPDRV, the input perturbation variables are TSFC, QSFC, TSKIN, PSFC, WS, TINP, QINP, and the output perturbation variables are TBMT, TBT2, TBMI. In the adjoint code ADMSPDRV, the input perturbation variables are TBMT, TBT2, TBMI, and the output perturbation variables are TSFC, QSFC, TSKIN, PSFC, WS, TINP, QINP.

8 References

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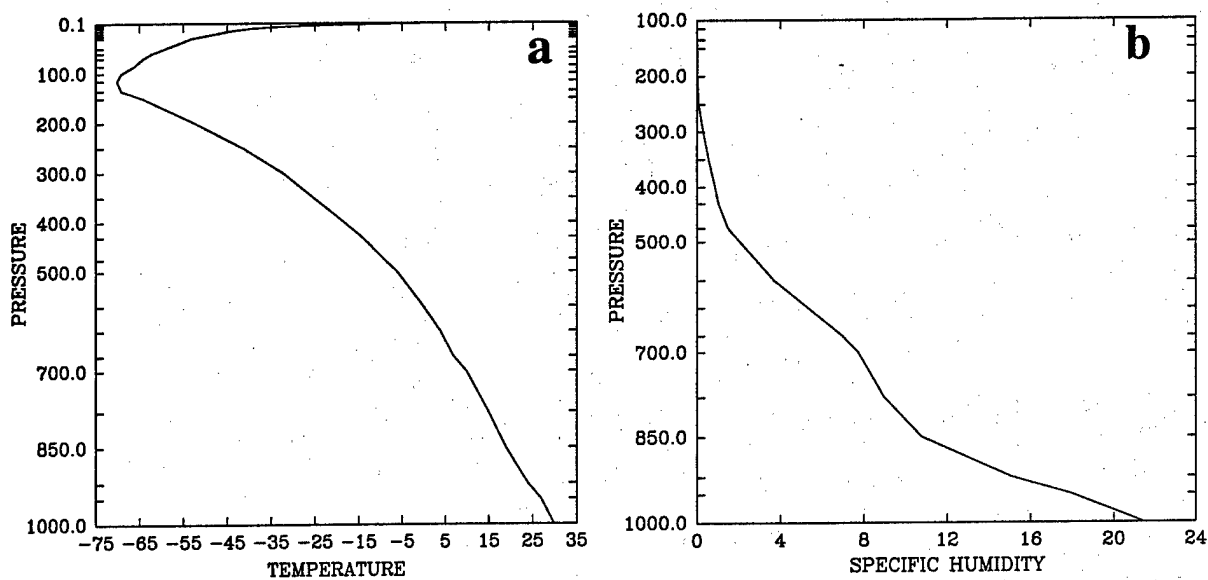


Fig.1 (a).Temperature (K) and (b). specific humidity (g/kg) profile used in the TGL and ADJ checking

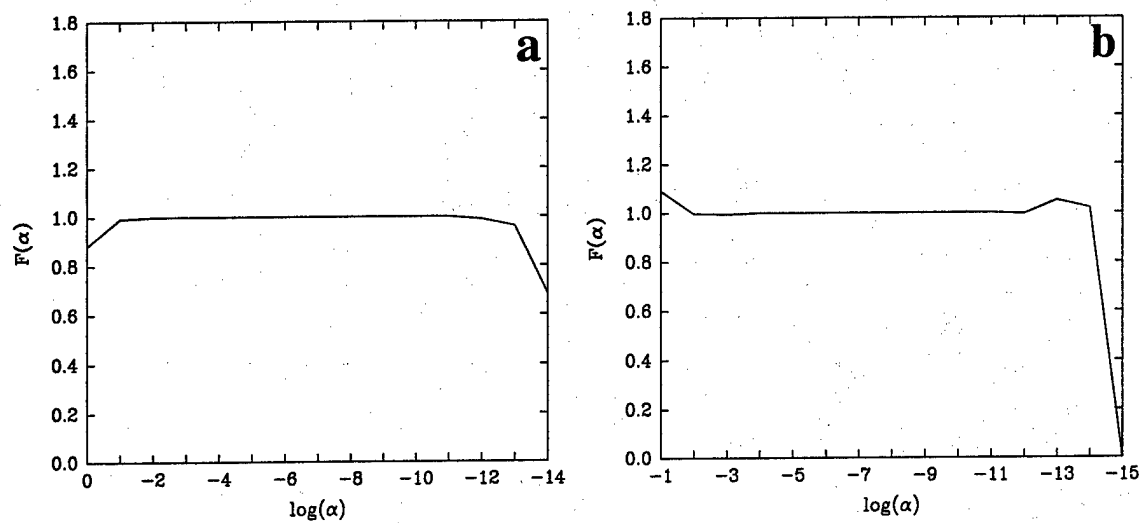


Fig.2 Variation of $F(\alpha)$ with respect to α in TGL code checking

a). SSM/T, SSM/T-2 and SSM/I; b). GOES-8